Mise en place du projet «changement climatique » de l'IPSL (Labex)

Le labex IPSL (L-IPSL) a un double objectif, scientifique et stratégique

L'objectif scientifique du projet L-IPSL est l'étude du changement climatique, en renforçant les travaux de la fédération de recherche IPSL, et en les intégrant avec ceux de deux autres laboratoires (IDES et SISYPHE). Il se décline en 5 « work packages » (WP) scientifiques et 3 WP transverses (TWP), décrits ci-dessous. Les objectifs des WP vont de l'étude des moteurs de l'évolution climatique, de sa prévisibilité, aux conséquences possibles de ces changements (ruptures, impacts), en développant l'observation, l'étude des processus et la modélisation à l'échelle globale ou régionale, et en quantifiant les incertitudes.

Stratégiquement, dans un contexte qui entraîne l'IPSL dans de multiples directions, le labex a en outre pour ambition de recentrer la dynamique de la fédération et d'accroître davantage sa visibilité tant nationale qu'internationale.

Le labex IPSL s'appuie d'une part sur les équipes et pôles d'expertise déjà structurés de la fédération IPSL historique (FR-IPSL) et, d'autre part, a pour vocation à être le catalyseur de nouvelles actions. Le labex développera simultanément un volet « recherche », un volet « innovation et transfert d'expertise » et un volet « éducation et formation professionnelle ».

Les moyens et la durée du labex (6.5 Millions d'euros sur 10 ans) vont considérablement accentuer la capacité de l'IPSL à lancer de nouvelles actions concertées et structurantes, en complément du nombre grandissant de projets répondant à des appels d'offre ciblés. Le labex associe deux nouveaux laboratoires (SISYPHE* et IDES*) dont la complémentarité scientifique vient renforcer la fédération IPSL.

Les WP scientifiques et transverses sont :

- WP1 Factors controlling the atmospheric composition
- WP2 The predictable part of climate evolution for the next decades considering anthropogenically induced changes and natural fluctuations
- WP3 The regional climate implications of global warming
- WP4 The expected impacts of climate change on natural resources and environmental changes
- WP5 The risks of abrupt unpredictable climate evolutions
- TWP1 Numerical modelling of the climate system (cf.pôle de modélisation de l'IPSL)
- TWP2 Strategy for observational studies: instrumentation, analyses, dissemination (actions instrumentation, observation et données de l'IPSL)
- TWP3 Assessment of uncertainty in climate diagnostics and projections

L'annexe I du document joint décrit la stratégie de recherche comme définie dans le projet initial. Les stratégies d'innovation et transfert d'expertise, d'enseignement et formation professionnelle, comme définies dans le projet initial, sont également jointes en Annexe II et III respectivement.

Une organisation adaptée aux objectifs du L-IPSL

Le labex IPSL est un projet spécifique qui réclame une gestion financière clairement identifiée, et une action conforme à la proposition qui a été soumise au comité d'évaluation. Mais il a été conçu et est organisé en harmonie avec la structure de la FR-IPSL étendue aux deux nouveaux laboratoires, structure qui porte le projet de labex. Ainsi, les tutelles de l'IPSL* et son comité de direction (CD), qui regroupe les directeurs des laboratoires de la FR-IPSL, et les responsables de pôles, fournissent le cadre de l'action du labex. Pour les besoins du labex, le CD est élargi aux directeurs des laboratoires IDES et SISYPHE. Le directeur du labex est aussi le directeur de l'IPSL. Le CD élargi est l'organe décisionnaire pour les actions du labex et l'attribution du financement des actions.

Afin de mieux coordonner les actions scientifiques, le CD élargi s'appuie sur les avis et propositions d'un Comité Recherche (CR) qu'il a nommé. Ce comité est composé de :

- 8 responsables de WP, dont la mission est la coordination des actions de chaque thème, le suivi et le reporting, avec un mandat de 2 ans, assistés chacun de suppléants,
- 9 experts transverses, dont la mission est de développer la transversalité des actions, nommés pour 3 ans,
- un président qui synthétise et constitue le contact avec la direction du labex.

Afin d'assurer une meilleure coordination entre les travaux du CR et ceux de la fédération, les responsables du pôle de modélisation et des actions–Observations – Instrumentation- Données de l'IPSL sont également responsables des WP transverses 1 et 2 du labex.

Le CR a une double mission : i) organiser une prospective scientifique sur le thème du changement climatique et ii) proposer et suivre les actions qui en découlent, en proposant au CD un budget détaillé.

Le CR proposera notamment:

- un ensemble de programmes dédiés (par exemple invitations de scientifiques, organisation de séminaires, …)
- un ensemble d'actions scientifiques de recherche, résumées dans un plan d'action, réactualisé tous les 2 ans.

Le CR fera le lien avec les équipes scientifiques du labex pour construire ces propositions en organisant des échanges (réunions, consultations, …). Les programmes seront ainsi établis grâce à cette approche par construction collective et non par appels d'offres comme les agences de financement de la recherche.

Le CR évaluera également la pertinence scientifique des autres actions du labex (éducation et formation professionnelle, innovation et transfert d'expertise) et pourra être force de proposition.

<u>La première année (2012)</u>

Mise en place d'une prospective à court et moyen terme

La mise en place de la prospective s'organise progressivement depuis l'automne 2011, et se poursuivra jusqu'au printemps 2012. Les différentes étapes sont en cours d'élaboration et vont inclure i) une présentation du labex sur les différents sites/laboratoires, au cours des mois de janvier/février 2012, ce qui permettra un échange d'informations et de recueillir suggestions et idées, ii) ainsi que des réunions ou consultations par les responsables de WP.

Un plan d'actions scientifiques à moyen terme (horizon mi 2014), ainsi qu'un plan prospectif à plus long terme, sera élaboré au printemps 2012 par le CR et proposera au CD élargi un budget de dépenses applicable dès la rentrée de septembre 2012, pour deux ans.

Programmes initiaux

Afin de lancer rapidement les activités du labex dès le début 2012, le CD a demandé au CR de proposer des programmes initiaux portant sur environ la moitié du budget 2012. Quatre actions sont retenues et ont été diffusées via les directions de laboratoires et de l'IPSL:

- un programme de scientifiques invités,
- un appel à projets de collaborations des laboratoires IDES et SISYPHE avec ceux de la fédération IPSL, pour accélérer l'intégration des travaux de ces deux laboratoires avec ceux de la fédération,
- un appel à projets initiaux transversaux pour développer les infrastructures de l'IPSL (TWP1 et TWP2)
- la mise en place d'un programme de séminaires IPSL/L-IPSL sur les thèmes du Labex.

Innovation, transfert d'expertise, éducation et formation professionnelle

En parallèle des programmes initiaux seront également mis en œuvre pour les actions enseignement et valorisation à l'initiative du CD. Ces actions seront évaluées par le CR.

Les contacts du labex L-IPSL

Directeur du labex L-IPSL: Hervé Le Treut (directeur IPSL)

Comité Recherche : Robert Vautard (LSCE, Président), Philippe Ciais (LSCE, resp. WP1), Eric Guilyardi (LOCEAN, resp. WP2), Cyrille Flamant (LSCE, resp. WP3), Agnès Ducharne (SISYPHE, resp. WP4), Franck Bassinot (LSCE, resp. WP5), Jean-Louis Dufresne (LMD, resp. TWP1), Philippe Keckhut (LATMOS, resp. TWP2), Pascale Braconnot (LSCE, resp. TWP3), Laurent Bopp (LSCE), Josette Garnier (SISYPHE), Jean-Michel Hartmann (LISA), Frédéric Hourdin (LMD), Christof Janssen (LPMAA), Kathy Law (LATMOS), Béatrice Marticorena (LISA), Jean-Luc Michelot (IDES), Benjamin Sultan (LOCEAN).

Experts invités, suppléants (liste provisoire) : Philippe Bousquet (LSCE), Cathy Clerbaux (LATMOS), Christophe Colin (IDES), Philippe Drobinski (LMD), Marion Gehlen (LSCE), Nicole Papineau (dira dj. IPSL), Christophe Rabouille (LSCE), Yao Té (LPMAA), Bruno Turcq (LOCEAN),

Les représentants des actions du labex participeront à un bureau qui se réunira pour préparer les réunions ou finaliser des décisions.

* Tutelles IPSL
CNRS, CNRS, CEA, Ecole Normale, Ecole Polytechnique, IRD, MNHN, Universités : Pierre et Marie Curie (P6), Versailles Saint Quentin, Denis Diderot (P7), Paris-Est Créteil (P12), Paris Sud (P11)

* Sites web des laboratoires SISYPHE et IDES et de la FR-IPSL
http://www.sisyphe.upmc.fr/
http://ides.geol.u-psud.fr/
http://www.ipsl.jussieu.fr/

Annexe I: Projet Scientifique, extrait du projet L-IPSL accepté

Les références figurant en Annexe IV

The L-IPSL project

The objective of the L-IPSL project is to assess and improve the French capacity to predict climate evolution at the time scale of a few decades and to determine some of its regional consequences, particularly in terms of environmental resources. This objective is ambitious, and significant progress is expected within the next 5 or 10 years.

To tackle this very ambitious challenge 5 major hurdles were identified above, both for their scientific relevance, and because of the specific capacity of L-IPSL to address them, thanks to the dual culture of modelling and observational studies that is characteristic of L-IPSL laboratories. They will define the 5 scientific work packages (WPs) that will structure the LabEx proposal.

Transverse, methodological work packages (TWPs) are also necessary to deal with the development aspects of the model architecture, to establish how the observational analysis and strategy should reflect the key objectives of L-IPSL, or to determine a consistent approach of the uncertainties affecting all the results.

Work packages (WPs)

WP-1) Factors controlling the atmospheric composition

The future evolution of the Earth radiative forcing will depend upon anthropogenic activities, reflecting economic development pathways and the structure of energy production systems, as well as the response of natural biogeochemical cycles.

Over the past two decades, 80% of the increased radiative forcing is caused by the emissions of CO_2 from fossil fuel burning and land use change. This illustrates how crucial is the **carbon cycle** in controlling the future rate of climate change. Roughly half of these anthropogenic CO_2 emissions are absorbed by natural sinks in the ocean and in terrestrial ecosystems. But models of the coupled climate-carbon system, such as those of the C4MIP experiment, consistently predict that future climate change will reduce the ability of natural sinks to continue to absorb anthropogenic CO_2.

Like the carbon cycle, **other long lived greenhouse gases** with a global warming effect, CH_4 and N_2O, also have an anthropogenic and a natural component, which are important to quantify and understand, including the underlying processes

Short-lived aerosols and reactive gases are produced by a variety of processes and transported away from emission regions. Unlike long lived greenhouse gases, these species exert a regional climate forcing, which can be either positive or negative in the case of aerosols. Locally, the climate forcing of aerosols and reactive gases can be larger in magnitude than that of greenhouse gases. Measures to improve air quality worldwide may release the ‘aerosol brake’, and foster the warming induced by greenhouse gases.

The science of the Earth System is still in infancy in its ability to describe and undestand the economic forces and the natural processes controlling atmospheric composition changes, in the recent past, the current decade, and into the future.

Given the modest resources allocated to a LabEx, this workpackage on atmospheric composition and radiative forcing cannot pretend to address the whole complexity of model development, model validation and model-data integration. Rather, we have chosen to focus our activities around three main outstanding research questions during the next 5 years. Each question will be tackled by using an integrated approach that combines both observations and models.

Question 1: Can we **attribute the radiative forcing of increasing atmospheric CO_2 and CH_4 to the underlying regional processes?** For example, can we discriminate the separate effects of the natural carbon cycle (e.g. CO_2 fertilization, nitrogen and water availability to plants, ocean biota changes) and to the economic drivers of fossil fuel emissions?

Question 2: Can we **attribute the radiative forcing of aerosols and short-lived reactive gases to their precursor emissions?** The main goals are to separate anthropogenic and natural sources, and to identify the relative contribution of different continental regions, using large scale transport-chemistry models, and inverse methods.

<u>Question 3</u>: What are the covariations between the regional **climate effects of aerosols and reactive gases and the natural greenhouse gas fluxes**? For instance, how does the climate cooling induced by sulfate aerosols downwind of industrialized regions or the exposure to high ozone levels, impacts forest primary production, which may limit carbon uptake by forests?

<u>Question 4</u>: Can we provide **a full uncertainty budget for the biogeochemical components of Earth System models**, and effective ways to reduce these uncertainties by using observations? For instance, can we reject and improve carbon-climate models of the C4MIP suite, and coupled climate-atmospheric chemistry models by using satellite observations (e.g. IASI, GOSAT, and forthcoming GHG space observations), in-situ ocean and terrestrial measurements and ground-based observations, such as ICOS for greenhouse gases, IAGOS for reactive gases, and EARLINET for aerosols.

Each question will be addressed by forming a project team, tasked to write a concise and realistic work plan, combining LabEx resources and resources from existing or forthcoming EU and national projects, with the goal to deliver research breakthroughs. The criteria for success and evaluation will be A-ranking publications, attractiveness to PhD and post-docs, and a number of successful projects created by each team. The emergence of new outstanding questions that may be incorporated in future steps, will be favored by organizing / contributing to meetings.

WP-2) The predictable part of climate evolution for the next decades considering anthropogenically induced changes and natural fluctuations

A large component of the recent global warming is now attributed to human activities. Global warming will continue during the next decades at a rate depending primarily on the anthropogenic emissions discussed in the previous section. However, the mechanisms and the respective role of internal variability, of natural or anthropogenic forcings on most aspects of recent climate changes (such as sea-ice decrease in the Arctic and precipitation changes in the Sahel) are currently not established. This lack of understanding limits our ability to predict climate evolution over the next few decades.

For the future, the predictability of regional climate for the next decades to century will primarily depend on three following points (e.g. *Hawkins and Sutton 2009*):

(1) the response to changes in long-lived greenhouse gases. This response highly depends on climate feedbacks for all time scales and therefore on how the various processes are represented in climate models. The emission scenarii will have little influence over the next few decades but a much larger influence at the end of the century

(2) the response to regional changes in aerosols and other short-lived species. Indeed, the geographical distribution of the associated radiative forcings is very heterogeneous, with strong forcings often close to densely populated regions

the low-frequency modes of natural variability (eg ENSO, Atlantic Meridional Circulation...). This requires these modes of variability to be well understood and simulated in models in current climate but also under climate change. For the near future, this also requires to accurately initialize the model, which requires good quality observations as well as appropriate initialisation techniques for coupled models.

In view of these major scientific and societal concerns, L-IPSL will focus on three related key objectives:

- **Quantify and understand the internal and natural variability of climate.** Climate varies at all time scales, from days to hundreds of thousands of years. The frequency and amplitude of these changes are very variable. They are mostly irregular in time and can be slow or abrupt. They often involve the various components of the Earth system and complex interactions between them. Understanding these climate fluctuations, their dependencies on the mean climate state and their response to external forcings is of prime importance to understand and to anticipate possible future climate change – and how an anthropogenic signal may be superimposed. This is already addressed within IPSL by considering a wide range of time scales *using both model and observations*. **Under this L-IPSL labex, a specific effort will be devoted to the study of the last millennium,** a period for which high-temporal (decadal to sub-decadal) climate variations may be reconstructed from various natural archives (*Jones and Mann 2004*), and for which some estimates of forcings associated with solar variations and volcanic eruptions are available (e.g. *Muscheler et al. 2007*). Understanding the natural, high-frequency paleoclimate variability will benefit from the recent progress in **observations of the ocean variability** (deep corals, molluscs), which give access to the direct recording of multi-annual to decadal changes. In particular, an important task will be to bring together paleoclimate data and recent observations in order to better unravel the natural variability of key oceanic features such as the **Atlantic Meridional Overturning Circulations**, its relation to mean climate conditions and its sensitivity to forcings. Another important effort of L-IPSL will be **to improve our understanding of the sun-chemistry-climate interactions** and, therefore, of the role of solar activity on climate variability. Recent and future observations of the solar activity and of stratospheric characteristics as well as modelling of chemistry-climate interactions will make it possible to identify and quantify the contribution of different processes.

- **Quantify and understand climate changes due to anthropogenic forcing.** The change in atmospheric composition is the main driver of human-induced climate evolution. The GHG radiative forcing is positive and determined with a reasonable accuracy. By contrast, aerosol radiative forcing is subject to a larger uncertainty. During th 20th century, it may have attenuated the GHG warming by 20% to 50% (*Forster et al. 2007*). This attenuation effect is poorly constrained and raises a first question: **how might the aerosols radiative forcing change in the future?** Even if the anthropogenic forcing was perfectly known (a case that could be considered in idealised numerical experiments), our estimate of the global warming may vary by a factor two (the current dispersion of climate models) due to radiative feedback uncertainty (*Bony et al., 2006*). This raises a second key question: **what are the mechanisms that primary explain the spread of climate feedbacks?** Open questions also concern other climate parameters. In the tropics, the **precipitation change** estimated by different models varies both in sign and in amplitude, both over oceans and continents: what, then, are the respective roles of the atmospheric circulation, interactions with the surface (continent or ocean) or rain processes in these diverging results? How might the monsoons change? **Oceanic processes and circulation** (such as the Atlantic Meridional Overturning Circulation) may also be affected by global warming, with related questions on how this may modify both the mean climate conditions and their variability. **The possible melting of ice sheets** may strongly impact the sea level and the ocean circulation via fresh water flux (*Swingedouw et al., 2007*). Many of these questions are interconnected: **the L-IPSL treatment of those issues will first of all rely on the analysis of the international CMIP5 multi-model database** that includes a wide variety of numerical experiments (such as idealised experiments, future scenarios, 20th century reconstitution, paleoclimate simulations, and decadal projections). The L-IPSL will play a leading role in a number of specific projects: radiative forcing, cloud feedback studies (CFMIP), and paleoclimate modelling (PMIP). **Dedicated sensitivity experiments** using the IPSL models, or process-oriented model/data intercomparisons, will receive a particular attention.

Predict and assess climate changes at decadal time scales. Recent, ongoing and future climate changes result from a complex combination of natural and anthropogenically-induced variations. Unravelling these two contributions is a difficult challenge but necessary: (i) to identify and assess mechanisms that drive climate variability and trend and (ii) to increase our confidence in climate change projections. Addressing these questions requires a joint use of models and observations, and to consider the coupled Earth system as a whole. L-IPSL will enable us to sustain the long-term observations performed by IPSL, to reinforce its contributions to international networks, and to perform dedicated and coupled analyses of observations and model simulations. In particular, the possibility of forecasting the climate 1-30 years ahead will be tested. For such timescales, climate models need to be realistically initialized, in particular the low components of the climate system. Challenges lie in the choice of these observations and in the development of new methodologies of coupled model initialization.

WP-3) The regional climate implications of global warming

Characterizing the implications of global warming in terms of regional climate changes as experienced by the human societies is needed to make appropriate adaptation decisions. A major challenge for the L-IPSL project will be to investigate regional climate processes and their evolutions under climate warming and to reduce the uncertainties in future projections with a focus on a few key issues**:**

The anticipation of regional changes in rainfall and in the water cycle, which is a prerequisite for adaptation decisions concerning water resource availability. The L-IPSL project will in particular develop improved numerical models, focusing on land/atmosphere/ocean/aerosols interaction processes at global and regional scale, benefiting from the experience that will build up or be acquired in major regional projects such as AMMA, HyMex and ChArMex;

The anticipation of changes in extreme events such as heat and cold waves over Europe, storms or cyclones (with a focus on the Indian ocean), wind stagnations, droughts and heavy rainfall. The L-IPSL project will in particular provide a quantification of the evolution of climate extremes from the few past centuries into the next decades, using statistical analysis of instrumental and paleoclimate proxy records, re-analyses, and climate projections;

The anticipation of changes in the polar Arctic climate, where changes occur at the highest rate, and in particular where we expect to have stronger signals of climate change for climate model evaluation: The L-IPSL project will provide an integrative and comprehensive picture of observed changes through monitoring (sea ice, glaciers, permafrost, ocean circulation, water and carbon cycles, atmospheric composition), analysis of available observations and coupled climate modelling.

These challenges will be addressed, in each case, by a process-based approach with questions specific to each region under study. Over **Western Africa** and **Indian Monsoon regions**, the focus will be to understand the relative role of global coupled climate and regional land-ocean-atmosphere-aerosols processes and associated feedback loops in driving the changes in precipitation regimes at intraseasonal to decadal time scales (*Janicot et al., 2010*). Over the **Mediterranean area** and **Europe**, the focus will be to quantify the interactions between land surface, soil moisture, groundwater fluxes, sea and atmosphere (including aerosol composition), in order to investigate droughts and heat waves (*Seneviratne et al., 2006*). The role of land use changes will also be considered in each case. In the **polar Arctic region**, emerging issues concern the interplay between the retreating sea ice, the evolution of atmospheric circulation regimes [*Houssais et al, 2007; Francis et al., 2009*] and the modification of atmospheric composition. Their interaction with temperature over neighboring continental areas, their land surface and the hydrological and bio-geochemical processes linked to the permafrost melting will be studied. As a new challenge, the **representation of individual processes and their interplay in global and regional high resolution models** will be evaluated and improved.

Detection of changes in surface climate, dynamical weather regimes, and frequency and amplitude of extreme events will be carried out through **advanced statistical methods.** These will use both observations and reanalyses (benefitting of the framework of the future ERA-CLIM reanalysis), involving data rescue, reconstruction, and interpretation of historical archives, and high resolution records of past climate variability from natural climate archives (e.g. drought reconstructed using tree rings, speleothems, lake sediments).

Finally, the L-IPSL project will use the available and future capacity of **observing and monitoring regional climate changes** with fixed sites such as SIRTA (*Haeffelin et al., 2005*), regional or global networks (SECAO, CARAUS, ICOS, HYPERARCTIC, FONCE, NAOS) and a mobile observation platform (SOFRAEX, IAOOS), benefitting from new space missions (Megha-Tropique, EarthCare, among others). It will also exploit the development of novel approaches of water cycle monitoring based on water vapour stable isotopes, using new laser technologies for observations and improved modelling of stable isotopes within the earth system model.

Improved models and new observations will enable regional projections with uncertainty estimations for the next decades, through the ensemble approach provided by the participation of the international exercises like CMIP5 or CORDEX.

WP-4) The expected impacts of climate change on natural resources and environmental changes

The natural environment has been modified by human activities for centuries (deforestation, urban sprawl, river channelling, wetland drying, overuse of groundwater, overfishing in the coastal zone, pollution and waste disposal). A crucial question about climate change is to understand and anticipate its impacts on natural resources, ecosystems, and their services, in the wider context of anthropogenic stresses. By combining leading expertise in both climate and impact science, L-IPSL will be in a unique position to diagnose past and ongoing environmental changes, and provide scenarios for the future. To this end, a large fundamental research effort will be devoted to better characterize the processes which control the evolution of the environment, by combining observations, tracers, process studies, and a hierarchy of models developed within the L-IPSL. The upscaling from local to regional scales will be a key issue to fully benefit from the regional climate projections provided by WP.3, including major advances on extreme events, and the carbon and water cycles. Future environmental impacts will then be elaborated by combining the impacts of climate change to the ones of human activity evolutions (*Ducharne et al., 2007*), owing to well-established interdisciplinary collaborations with social sciences and stakeholders (e.g. GIS-Climat, PIREN-Seine, FIRE research federation, Climate KiC), as well as other Labex projects (ACTE, ODYSSEE, ARCTOS). In this framework, we will focus our efforts on four specific challenges:

- **<u>Impact of climate change and anthropogenic drivers on water resources.</u>** With a growing population, water resources (surface and ground water, including both quantitative and qualitative aspects) are largely under stress, especially in vulnerable regions such as Sub-Saharan Africa (*Roudier et al., 2010*), the Mediterranean surroundings, or South-East Asia. Anthropogenic influences (withdrawals, damming, etc.) also hinder climate change detection and attribution (*Piao et al., 2007*). **To separate these effects, L-IPSL will develop new approaches combining geochemical tracers, geophysical tools, and an array of models** developed for different scales, with important applications regarding ground water (renewal rate, overexploitation, salinization). This framework will also support the improvement of ground water and river discharge representation in the models of the L-IPSL. Owing to these conjugated actions, L-IPSL will be better armed to address past and future changes in water resources and hydrological extremes (floods and droughts), from the local to the global scales, and to **explore adaptation options** between different uses (irrigation, drinking water, navigation, industries, habitat for aquatic species, etc.).

- **Impact of climate change on biogeochemical fluxes and ecosystems along the land-ocean continuum.** Ecosystem functioning and their related services (carbon, contaminants and nutrient control; water quality; food production; green-house gas control) are very sensitive to climate. In the aquatic continuum from the upper watersheds to the estuarine/delta interface with the ocean, the changes in rain pattern and intensity, and the frequency of extreme events (heat waves, freezing, drought, floods, etc.) are the main drivers of erosion and leaching, and of material transfer, retention and transformations. In the open ocean, acidification and changes in ocean circulation and stratification could provoke important changes on marine ecosystems, their productivity and fluxes. **A challenge will be to extend the specialized models of the L-IPSL** (e.g. *Garnier et al., 2010*) to the global scale, and to extend the ocean modelling to critical segments of the trophic chain. These developments will be supported by combination of *in situ* observations, process studies with new tracers to assess models. They will largely rely on the Equipex PACEC and SeineARIO, and on collaborations with the Labex ODYSSEE. **Retrospective analysis of human and climatic impacts** on aquatic ecosystems will be carried out over the last centuries. It will serve as a valuable validation of the proposed approaches and as an essential reference to assess **future changes**.
- **Impact of climate change on energy resources and infrastructures.** Local climate is a key factor for renewable energies (wind power, solar energy, hydro-electricity, bio-fuels) and an important limiting factor for non-renewable ones (plant cooling, efficiency of geological storage options for CO_2 and radwastes). Extreme events (storms, floods, droughts, hot spells) are also crucial to the vulnerability of infrastructures, as well as permafrost melting in Arctic areas. The L-IPSL will offer a significant contribution to this emerging research field by providing **comprehensive diagnostics, with likelihood/uncertainty assessment,** of climate change impacts on the energy sector, using global and regional projections from the IPSL models and retrospective analyses (*Vautard et al., 2010*). These diagnoses will then be used to develop adaptation and mitigation strategies in relation with IEED CLAIRE.
- **Impact of climate change on sources of regional and global air pollution.** Climate change has an impact on air pollution through a variety of processes: changes in atmospheric chemistry, aerosol formation, changes in transport and dispersion, stratosphere-troposphere exchanges, and changes in biogenic (vegetation) and natural sources (dust, fires). Air quality is also changing due to evolution in anthropogenic emissions, linked to population growth/wealth as well as to energy use patterns. Biogenic emissions are also impacted by land-use change and practices (*Coll et al., 2009*). In return, such emissions depend on human activities influenced by climate. Current knowledge of emissions has large uncertainties. In order to improve regional and global evolution of air quality, the L-IPSL will focus researches on **sub-grid scale variability and a better understanding of possible feedbacks between atmospheric concentrations and emissions.** Better flux estimates (spatially at the regional and global scales, and temporally on annual, seasonal, daily and hourly time scales) with associated uncertainties will improve results on trends analysis and scenarios for the future. **Emissions for gases and aerosols, which depend on dynamic vegetation, land-use change *and* climate model variables, need to be developed**. The provision of emissions at ever increasing spatial and temporal scales requires efficient database structures with interactive processing which build and extend existing capabilities developed at national, European and international level.

WP-5) The risks of abrupt unpredictable climate evolutions

In the previous sections, we have made the implicit assumption that the behavior of the climate system would remain rather regular, and that the anthropogenic component would linearly add up to natural climate variability, e.g. that is strength would be dimensioned by the future evolution of the radiative forcing. But a more complex behavior is possible. Past climate archives have documented many dramatic changes and bifurcations, occurring sometimes in less than a few decades, which clearly attest the nonlinear nature of the Earth's climate system and the existence of multiple equilibria and tipping points, that determine the risk of abrupt transitions (*Rial et al., 2004; Lenton et al., 2008*). Reaching such tipping points may occur within the current century, possibly triggering yet unpredictable, rapid evolutions of the climate system. Potential mechanisms are related to ocean circulation changes, ice sheet instability, carbon storage and CH4 release from permafrost, major changes in the water cycle with increasing desertification and modifications of the biosphere (as may have happened over the

Sahara 5,000 years ago. Those potential drivers can be illustrated, here, by one example, that of the dramatic swings, which involved changes in the North Atlantic oceanic circulation. These changes result from the extreme sensitivity of this ocean to the fresh water budget, and from its additional capacity to trigger potential positive feedbacks (clathrate destabilization, change in planetary albedo).

The perspective of such dramatic evolutions has raised a large amount of public concern, and the role of L-IPSL will be to document the conditions in which they may occur by tackling two major questions:

(i) What are the potential mechanisms for abrupt changes?

(ii) How can we determine that we are nearing the conditions in which this may happen?

To answer those questions, past climates, and climates of other planets provide important references to investigate the relevant mechanisms, and quantify positive and negative feedbacks. They make it possible to address thresholds and tipping points with special focus on ice sheet instability under warming conditions, ocean circulation reorganization under variable fresh water fluxes, carbon release from permafrost and biosphere, volcanic eruption frequency and punctuated cooling associated to aerosols. Based on this knowledge, enhancing our capacity to predict future climate bifurcations will require to better integrate feedbacks and nonlinearities in climate models (i.e. more accurate ice-models) and conduct data-model comparisons as well as detailed inter-comparison of model outputs (PMIP–like approach).

The needed large-scale research efforts exceed the frame of L-IPSL, and are subject to numerous international research efforts in which we participate. At the L-IPSL scale, however, we gather a unique force of expertise to advance very significantly our knowledge by focusing on a few scenarios, which carries a greatest likelihood of causing abrupt climate changes during the next century:

(i) Abrupt cooling situations during interglacial conditions (for example, the 8.2 ka BP event, or the Younger Dryas), which give indications on the possible future disturbance of the Atlantic circulation;

(ii) Abrupt warming situations during glacial conditions, which tell us about the processes, which may potentially affect the polar ice sheets;

(iii) Rapid variability during past interglacials warmer than the present day (e.g. MIS 11, polar climate during the last interglacial), which may constitute a partial analogue to the situation of the next decades.

One objective is to improve -the acquisition of paleoclimatic information –especially obtain high resolution information (the need of high resolution information was explicitely stated in the last IPCC report) and use this paleo-information into transient, long climate simulations in an attempt to benchmark climate models against transient sequences of events, on time scales which are relevant for future climate risks (e.g. centuries). The IPSL model is considered a state of art model in climate science, but its capacity to generate realistic climate swings has not been fully assessed. It will be improved by a better integration of key non –linear processes (ice dynamics, snow representation, carbon cycle in the atmosphere, the continents and the oceans, ocean deep water formation).

This allow for exploring the potential climate bifurcations that might occur at the century scale.

Achieving this objective will only be possible though the integration of the L-IPSL obervationnal and instrumental capacity. A strong partnership already exists between L-IPSL members and recent successful or planned initiatives (SESAME-ALYSES platform, ERC-ICEPROXY, MC-ICPS, PACEC equipex project) allow for the creation of a state of the art analytical platform.

This joint effort will favour a dramatic improvement (in number, quality and type) of key climate parameters paleo-reconstructions through a better understanding of signal acquisition, and the developpement/improvement of new proxies (ocean circulation, sea ice, precipitation, winds).

This state of the art equipment will also allow for the development of chronologically well-constrained (radio-, magneto- and tephro-dating) multi-variate database to reconstruct high-temporal resolution, transient sequences of events.

This capacity to reconstruct past climates (or climate of other planets) constitutes an outstanding feature of the IPSL federation and will warrant that L-IPSL will use original high quality observational information to evaluate the possible occurrence of rapid climate fluctuations during the next century

Transverse work packages (TWPs)

TWP-1) Numerical modelling of the climate system

The ability to better understand and to anticipate the modifications of climate on decadal timescales and beyond depends for a large part on major developments and improvements of the predictive capabilities of climate models. In the absence of established analogues of GHG-driven climate change, numerical modelling based on a physically-based representation of the key processes and components that govern the dynamics of the climate system is increasingly recognized as the most valuable approach to anticipate the future climate changes, at both global and regional scales, and to improve the predictive capabilities of climate models. IPSL is currently one of about ten climate modelling centres in the world that develop Earth System Models (ESM), and has a leading position in many of these aspects (such as ocean modelling, carbon-climate coupling and cloud feedback studies).

The L-IPSL project will address the following key issues, in order to improve and develop more comprehensive climate models.

Improving the representation of physical processes and their couplings: The inclusion of new interconnected components (carbon cycle, chemistry and aerosols) into climate models and the need of more reliable regional climate-change projections require improved representations of the basic physical processes, both in the atmospheric and oceanic circulation models of ESMs. For instance, precipitation is an essential characteristic of a regional climate and is critical for the coupling with other components and for water resources. However, precipitation is currently not well simulated in climate models (*Hourdin et al. 2010*). Therefore, special effort will be made to **improve the representation of cloud-convection-turbulent processes** in the IPSL climate model (*Marti et al., 2010*) based on the development of new parameterizations (*Rio et al., 2009*, *Grandpeix et al, 2010*). Attention will be paid to the representation of the radiative effects of climate-forcing compounds (e.g. aerosol direct and indirect effects). This will be accompanied by an **improvement of land-surface representations** (vegetation, subsurface hydrology, snow...) and the generalised inclusion of water stable isotopes in the models as a powerful tool for process and climate evaluation. IPSL is also at the origin of the NEMO consortium that develops the ocean model currently used in many international climate models. The **improvement of key oceanic processes** (coastal upwelling, vertical mixing at high latitudes) and of the fast coupling with the atmosphere (cyclones, diurnal cycle) will also be a major step forward in the realism of the coupled-climate model. Another step towards a finer representation of physical processes at regional scales is the **development of regional coupled models at higher resolution** (up to a few kilometres over zoomed areas). It should improve our understanding of scale interactions and the reliability of the projected potential impacts of climate change at regional scales.

Improving the representation of biogeochemistry processes and their coupling with physical processes: To account for the potential feedback between biogeochemical cycles and climate, new components (carbon cycle, chemistry and aerosols) have been included in Earth system models. They are developed and assessed separately or in less interactive configurations in order to identify the processes directly influencing climate but also to improve the understanding of biogeochemical cycles or the radiative effect of each climate forcing agent. Hence, **to better represent the ability of natural sinks to absorb anthropogenic CO_2, key processes will be included/improved** (land-vegetation phenology, phytoplankton physiology, carbon-nitrogen cycle interactions) in the terrestrial and oceanic carbon cycle models. Beyond CO_2, **other climate forcing agents** (aerosols, methane, ozone, N_2O…) **will have to be more explicitly represented**, which requires both interactive atmospheric chemistry and representation of biospheric fluxes (oceanic DMS or VOC production as well as methane production by anaerobic soil respiration). These developments will not only lead to a better climate-sensitivity quantification but also to the understanding of the environmental vulnerability to climate change. Hence issues such as the impact of oceanic acidification on marine ecosystems, air pollution and its subsequent health impact, and agricultural vulnerability or adaptation will be investigated thanks to these components.

Developing new algorithms and models to take advantage of new computer performance: Increased computer power in the next years is expected to come from new architectures and an increased number of CPUs. A major effort will be made in **rewriting the “dynamical cores”** of the atmospheric and oceanic models, using new approaches (e.g. finite volume on “cube spheres” or “icosahedral grids”), in **developing new tools** for the Inputs-Outputs and model infrastructures. The increased power will enable increased model complexity, resolution, and the number or length of the simulations. The **development of high-resolution models** will be of direct interest for many climate uses but also to answer important questions of geophysical fluid dynamics both on Earth and on other planets: the role of frontogenesis in the general circulation, dynamics of super-rotating atmospheres (Venus, Titan) and giant planets.

TWP-2) Strategy for observational studies: instrumentation, analyses, dissemination

The work packages 1 to 5 defined above mostly rely on a combination of model and observational studies. IPSL has a strong potential for research concerning Earth observation (about 60 researchers and 50 support staffs). The instrumental and observation strategy of L-IPSL relies on this capability.

The main evolution within the next 10 years will be to handle the interdisciplinary dimension of environmental research with partners in hydrology, ecosystems, medicine, and economics.

This will require new observations and measurements, taking advantage of next-generation sensors and improved laboratory analytical capacities, and therefore of **an important R&D programme, including: prototype instrument** development and realisation**, the calibration of instruments or sensors,** which will likely demand acquisition or calculation of **new molecular spectroscopic data, and development of data processing** methods (retrieval, algorithms), and the development of utilization methods**.** These progress will benefit from the various EquipEx proposed by the L-IPSL laboratories such as GHG-Scope, SOFRAEX. **The L-IPSL priorities will help coordinate these efforts and distribute them over different types of vehicles or analytical platforms** (ground-based instruments, balloon and airborne sensors, autonomous ocean systems, space observations, platforms in the laboratories). For example, the result of WP-1 may be that the determination of surface carbon fluxes imperatively requires the measurement of CO2 with a precision of a few ppmv, requiring in turn the improvement of the capacity of instruments on board satellite missions like IASI/MetOp, or lidar, instruments or laser diode sensors. On the other hand,to achieve such precision, observation of CO2 required unprecedented challenges on the quality of the underlying spectroscopic data. Similarly, future high precision molecular spectroscopic data on water vapor and ozone isotopes are prerequisites to realize novel approaches of global monitoring of cycles. Instrumental development, observations and data analysis must thus be accompanied by the next generation of experimental and theoretical molecular studies in the laboratory.

The L-IPSL project will also require some enhanced analysis capacity to improve the synergy between models, and models and data, in a few areas:

New strategies for observation and analysis of multi-parameters series. The synergy between a long series of parameters observed through different sensors is the key to the development of application-oriented studies. The challenge is multiple: there is first a need to define and optimise in situ networks, link them together on specific sites, and define the nodes between several complementary networks. This type of synergy has been developed through the ongoing European GEOMON project and will continue, for example, with the project SOFRAEX or GHC–Scope recently proposed in the framework of the EquipEx. In the Tropical area (focus on West Africa, the Indian ocean and South America), active collaborations will allow for studying the water cycle including in situ and satellite (SMOS) clouds and water vapour from a variety of means (lidar techniques, laser diode for isotopic composition, satellite observation with Megha-Tropique) to better analyze the variability mechanisms and feedbacks from the surface. The in situ data or aircrafts/balloons observations will also be used to validate space-borne instruments and to diagnose model deficiencies using observation simulators.

Long-term in situ and satellite observations on a decadal scale. The new availability of these time series also brings new scientific opportunities and associated challenges. The continuity of the measurements is necessary to ensure a significant estimate of inter-annual changes and the detection of an anthropogenic component, with a considerable effort to determine the data series on a global scale through the adjustment of successive sensors following international standards (GEO/WMO), or to use the complementarities and synergies between satellite and in situ observations. This corresponds to work that is carried out at the international level, with the participation of IPSL laboratories, for example for clouds (ISCCP/GEWEX), ozone and temperature in the stratosphere (SPARC), and ocean (CLIVAR/IMBER). Although the existence of this work is a prerequisite for the L-IPSL project, the LabEx contribution will be more methodological, and will deal with analysis methods to extract significant climate change information from these time series. Such coupling will be performed using SMOS/ALTIKA-JASON missions together with SSS/Coriolis networks, CO2/CHG monitoring from the OCO, GOSAT, then Merlin, MICROCARB missions together with ICOS, Calipso / Earthcare, Megha-Tropiques / GPM missions on clouds and water cycle, together with SIRTA, and the projected SECAO network.

Long term observations of natural climatic variability and environmental changes. Climate variability requires to place the short instrumental period into the broader perspective offered by the evidence of past natural climatic and environmental changes and to learn from changes observed in the past to better understand and model the present processes. New scientific questions regarding pressures on our present environment, ecosystems and societies necessitates the development of new scientific strategies to better understand the sensitivity to climate of continental hydrology, environmental transfers and processes on land and in the ocean, These challenges require the building of a beyond state-of-the-art analytical capacity, which is proposed in the framework of the EquipEx PACEC and the ALISES platform: multiple elemental and isotopic proxies, higher accuracy measurements, high resolution temporal and spatial analysis, new tracers and archives, improved calibration, in the perspective of better integration between data and models.

Intensive observation campaigns are the only way to accurately document specific events or processes. The L-IPSL project will focus its activity on a small number of national and international campaigns:

The Ile-de-France area, which is appropriate for hydrological and air-quality studies based on the OASIS (UPEC) and QUALAIR (UPMC) platform complementing the SIRTA, in addition to the Piren-Seine hydrologic observing sites.

The Mediterranean area, a key area to test emerging regional Earth System Models (HYMEX/CHARMEX/MERMEX).

The Arctic area, where the climate-change signal is the stronger and the most rapidly increasing. Several field activities will be planned through the INSU Arctic programme within the next 5 to 10 years (Siberia, North Canada, Svalbard, North Pole). These campaigns will benefit from the proposed instrumental systems (EquipEx IAOOS, ANR OPTIMISM) and will include paleoclimatological activities (permafrost, ice sheet, sea ice).

One of the other challenges consists in developing **added-value products through well documented, interoperable databases,** but remaining independent to preserve their specificities as suggest through the GEOSS/GMES strategy. IPSL has the capability to actively contribute to this strategy, in interaction with the other French laboratories involved in each research field (e.g. the SECAO network for West Africa, which should combine climate / hydrology measurements with society-oriented products on resources) and through the national thematic poles (particularly ETHER, ICARE in which IPSL is strongly involved). Another promising issue will concern the Earth-sun relationship with, as the core mission PICARD. Database documentation and organisation will benefit from our partnerships within the GIS climate members coming from different communities.

TWP-3) Assessment of uncertainty in climate diagnostics and projections

The analysis of climate evolution, the detection and attribution of observed changes and the characterization of projected future changes are required for a rapidly growing number of applications. Some are associated with new scientific needs, at the interface between climatology and research areas such as ecology, economy, epidemiology; some others correspond to more applied needs for expertise, from private or public actors going from citizens to large companies, concerning primarily mitigation and adaptation policies at the international, national and regional levels. This increase of climate information use gives to climate science a new responsibility and therefore necessitates **strengthened strategies and methodologies for assessing the uncertainties associated to diagnostics and projections**. However, despite recent advances, this issue still requires specific research activity to properly discuss the different level of uncertainties and how they affect the results for different applications. Progresses in this direction are therefore needed to provide user relevant climate information and the associated expertise (see also section 5.2.2 below).

The aim of TWP-3 is:

To develop research on assessing uncertainties of climate information for impact studies,

To build up the expertise required for an effective use of modelled or observed meteorological and climate products and their uncertainties for various applications.

In the first case, research will benefit from the development of ensemble approaches and of statistical methods, such as the one promoted in the EU-ENSEMBLES project, to analyse the cascade of uncertainties from the large scale to the more regional of local scale of interest for the impact studies, In the second case, the expertise will be based on interdisciplinary projects, and the questions will be identified and addressed in a very tight discussion with the “user side” community. This will benefit in particular from the “Paris Consortium on Climate – Environment and Society”, as well as form other projects such as the RExHySS, the GICC-DRIAS, ANR-SECIF or IS-ENES projects., where periodical workshops involved scientists and a wide array of concerned stake-holders.

This is a transverse activity in many ways. First the uncertainties arise from a sequence of processes treated in different WPs of this proposal: evolution of the atmospheric composition (WP-1), climate response to this forcing (WP-2 and WP-5), regional signature of global changes (WP-3) impact on resources (WP-4). Assessing uncertainties of climate projections also involves comparisons of the full Earth System Model results (TWP-1) with observations of the real world (TWP-2).

Develop methodologies to assess the uncertainties of climate diagnostics and projections

A first objective is to make use of scientific expertise developed in the different WP to improve the characterisation of model skill and the understanding of model uncertainties. This need to be grounded on model evaluation and requires making use of a wide range of observations and a diversity of methods: process-oriented multi-parameter verification, simulators of observing systems from model results. It also often requires an ensemble approach and comparisons of statistics such as mean, variability, PDFs etc.. usually requiring a ensemble simulations, where the climate model is run with a set of different initial conditions. In the L-IPSL project, observations will be systematically compared to a hierarchy of configurations of the IPSL climate model. Sensitivity experiments with different model configurations will be uses to understand the impact of model biases on the simulations of climate variability and trends. One may use for example climate reconstructions using the atmospheric model forced by observed sea surface temperature (which may be de-trended, or reduced to their trends) and by different specifications of atmospheric composition (constant or evolving), with or without nudging of the atmospheric large scale dynamics by “reanalyses”; coupled atmosphere-ocean models with or without modification of the atmospheric composition, etc. The same approach may be used for other components of the climate system **and the comparison of these ensembles of results with observations of the last decades will be used to asses the representation of both climate change trends and natural decadal variability, and to identify the main elements of confidence and sources of uncertainties in this complex system.** Simulations of past climate conditions and comparisons with paleoclimatic data will also be carried out to test the robustness of the climate model skill to large changes in forcing. Evaluation will also involve the development and use of complex statistical methods to establish for instance the geographical patterns of natural variability and long-term changes, or the occurrence of rare events. Uncertainties in our knowledge will also be assessed using model ensemble approaches, within the framework ofl European and international projects to which L-IPSL will be associated. As an output of these researches, a wide range of diagnostics concerning model performance and model relevance will be produced and distributed. This will be based both on qualitative expertise (based on the level of understanding of the different processes, as emphasized by the recent inter-academic report on the IPCC) and on more quantitative approaches using a basket of different metrics, with specific process-oriented analyses of model performances.

Impact-oriented climate model assessments

Depending on the nature of the impact studies, the importance of spatial scales and temporal variability can be completely different (seasonality, extremes, inter-annual or inter-decadal variations). In most cases, it is not clear to know a priori which will be the most constraining factor in the future evolution, or which is the particular combination of climate indicators or variables which will have an impact. In TWP3, we will promote the **development of integrated evaluation approaches, in which impact models (crop, water resources,...) interfaced with climate model outputs (either directly, or through *ad hoc* filtering or index computation) will be used to assess the climate model results**. The methodology will also be verified using reconstructions of the climate of the last decades from historical data, Exploring these questions and defining and assessing the best way to interface climate outputs with impact models in turn brings new insight and questioning on what climate numerical models can provide, new orientations for model improvements, new need for dedicated observation or observational strategy. For instance, the description of subgrid scale variability, which is often at the basis of climate model so-called “parameterizations”, is often lost in (global or regional) climate scenarios outputs, whereas it could be of great interest for some impact studies. This is for instance the case of the subgrid scale cloud or rainfall distribution, which is currently used for model evaluation and comparison with satellite data but not for impact studies. Such approaches will be developped in the context of international projects (CMIP, CORDEX), and the corresponding expertise will be transferred to users

Annexe II: Innovation et transfert d'expertise, extrait du projet L-IPSL accepté

Innovation and transfer of knowledge from the L-IPSL project

Strategic positioning

With the growing concern about climate evolution, a considerable interest for climate science has developed during the last decade. Climate research teams – and in particular IPSL – have built scientific knowledge and technical tools that give them the capacity to address some of these issues. This knowledge is at the cutting edge of science, and is progressing rapidly. It also carries major uncertainties, reflecting still inadequate knowledge of the earth system. A stronger and more integrated link between climate science and society is therefore required. This situation stirs a large demand for transfer and innovation. For example, climate change and air pollution issues are strongly connected, with European directives bringing new regulations, such as the National Emission Ceiling directive, and requiring adequate monitoring. At the national scale, the recent definition of regional and territorial plans in the French "Grenelle 2" are effective and require an anticipation of their integrated effects in the long term.

This interaction between science and society constitutes a new mission of institutes such as the L-IPSL, and at the level of the Paris or French levels, the LabEx synergy is absolutely necessary to address these challenges. Nothing can be done without the expertise of the major research laboratories in the field, but the task is enormous and even a research institute of the L-IPSL scale cannot handle it alone. The L-IPSL will need to design an adequate strategy to spread climate knowledge, and the associated tools and services, in which (1) it makes sure that its evolving expertise and the associated uncertainties and limitations, are fully taken into account, but also that (2) dedicated new structures are set up to provide the necessary help to confront a huge demand which is well beyond the capacity of L-IPSL alone.

In what follows we first give general indications on the L-IPSL potential (e.g. the areas in which it has the capacity to transfer knowledge and technology) and on the structural means and association through which it can act (also described in B.5 and B.6). A set of more specific examples is then reviewed.

L-IPSL potential for innovation; main partners

The capacity of L-IPSL to transfer knowledge and innovation concerns several domains:

innovative instrumentation for environment observation and monitoring;
innovative modelling for environment prediction;
distribution of climate information and associated uncertainties;
advanced mathematical (for example statistical) methods to combine observations and model results for monitoring, forecasting; downscaling or uncertainty assessment.

In each case, a specific strategy for innovation and the creation a value is needed.

The IPSL has exploited this potential for more than a decade by actively participating to major international monitoring programs such as the European GMES (Global Monitoring for Environment and Security) where it has transferred codes with operational capacity. The OPA/NEMO model is used at European level as a reference operational model for oceanography. The air quality prediction code CHIMERE has been transferred to INERIS, an operator, which uses it in the context of the French PREV'AIR prediction system.

To go further, L-IPSL will rely on strong existing links with industrial partners, a network of SMEs and public agencies. It can also benefit from the framework of the new European "Climate Knowledge and Innovation Community (KiC)" designed to link research, training and innovation at European scale to foster climate change adaptation and mitigation. At the national level, it will also lean on the new project of "Institut d'Excellence sur les Energies Décarbonées" (IEED) named Climate – AIR – Energy (CLAIRE), if funded, a major goal of which is to develop a center for climate and air services.

This strategy is detailed for different areas.

General expertise and transfer of knowledge

Climate-change economic actors need an increased knowledge in climate science, but also an acute understanding of the associated uncertainties. For example, the probabilities of exceeding thresholds in the occurrence of extreme events is necessary to determine the regional impact of emission abatement strategy taking into account climate change, or the regional carbon cycle monitoring. Yet, when addressing such climate change consequences, one has to deal with a large cascade of uncertainties (*Katz, 2002*), attached to emission scenarios, climate projections, and impact models. For the L-IPSL strategy will act simultaneous as a provider of basic knowledge, tools and data and to accompany these services by an uncertainty estimated specifically for each case study.

The strategy of the L-IPSL will be two-fold:

(i) to develop autonomous initiatives, relying on its strengths, or those of its sponsors to develop training programs with the universities or communication actions toward the public

(ii) to develop a stronger partnership with industries and SMEs and use them as vectors of knowledge transfer, in particular through non-academic partners. The IEED CLAIRE and the climate KiC are tools to develop this second approach.

Innovative observation technologies

L-IPSL scientific priorities concerning the monitoring of climate require the development of instrumentation for all possible platforms: ground based, airborne, within the ocean, from balloons or ships, from space missions. The observational strategy implies to monitor key parameters on the long term, with multiple parameters being observed and analyzed at collocated instrumental sites. The continuous development of innovative instruments and analyses is absolutely necessary to calibrate the measurement networks, increase their reliability. It naturally leads to a transfer toward SMEs or larger companies. Indeed, this transfer is necessary for long-term climate monitoring, which require development and operations of series of identical instruments. Based on developments of one or two prototypes by research laboratories, transfer of knowledge is necessary to ensure this long-term observing strategy. L-IPSL will strengthen collaborations, which have already been developed (particularly space projects), during their R&D phase and up to the definition of phase A.

Modeling and innovative methods

For modelling applications, the general strategy of L-IPSL will be to favour the use of its codes through open access, and help develop specific applications with SMEs, agencies and other industrial partners, through specific pilot projects whose products could be spread or commercialized, in particular through the partners of the IEED CLAIRE and the Climate KiC where pilot applicative projects and demonstrators can be developed. These specific applications will then be spread in a commercial mode for users via the SMEs and industrial partners.

The IPSL has developed an integrated global earth system model (ESM), which couples models of the various climate components, and off-line models, which can either be some versions of the ESM components, or autonomous systems (for air quality, continental surfaces, …). All models have been designed to address specific applications. Models are not necessarily based on deterministic equations. Innovative statistical methods - such as advanced time series analysis, downscaling techniques, inversion or data assimilation techniques - also carry a large potential for applications.

The offer of service concerning model studies should not concern the codes and the data bases only, but also the transfer of information and expertise for an optimized use. This will be favored by the organization of a user community (involving other academic laboratories, industries, SME or public decision makers), that will also use by themselves some of the offline components or impact models, thus providing incentive for an easier access to simulations, more explicit documentation.

Distributing the results of climate research and their uncertainties

Distributing the results of climate research constitutes a new mission for institutes such as IPSL. This distribution is now an international task. Data amounts are huge (1 Petabyte for the sole IPSL model in preparation of the next IPCC AR5 report). The complexity of the task should grow by one order of magnitude every 5 years. Distribution uses standardized international technologies, because the international community is evolving from the use of a central facility to the development of an international distributed database, for which IPSL will be a distribution node.

Over the next 5 years, **L-IPSL will develop a perennial dedicated facility** (based on the PRODIGUER and DRIAS projects, with the ability to constantly adapt to growing requirements), and to maintain an active participation in the definition of international standards (such as metadata, format and security). This is essential to the credibility and international positioning of L-IPSL. It will constitute a transcollaboration across the different L-IPSL laboratories and services. Its target will be to improve the quality of the data distribution to users, and reversely, to improve the quality of the models by organizing a continuous “return of expertise” from the users.

The uncertainty attached to climate information requires a dedicated scientific approach, and tailored analyses (see work proposed in TWP-3). **The diffusion of model and observational results, the communication of the associated uncertainties, in close collaboration with other institutions at the national and international level, will be a priority of L-IPSL**. **A major effort will be made to offer a wide range of diagnostics concerning model performance and model relevance**. This will be based both on qualitative expertise (based on the level of understanding of the different processes, as emphasized by the recent inter-academic report on the IPCC) and on more quantitative approaches using a basket of different metrics, with specific process-oriented analyses of model performances. A prototype for such an approach is under development in the FP7 IS-ENES project to prepare an e-knowledge service at the European level, designed to bridge climate research data and the needs of the various communities requiring climate information. L-IPSL will produce a greatly increased amount of information over the next ten years, and one of its main tasks will be to develop an **“interface research team”** able to customize and transfer this expertise.

Monitoring the earth system

The future development of our societies and its crucial implications for the next generations will strongly depend on environmental policies The information provided by a careful monitoring of climate parameters is essential for decision makers or citizens who design or vote for those policies. This transfer of information is already taking place. For example, the information provided by the European Earth observation program GMES will increasingly be used by policymakers and public authorities, to prepare environmental legislation and policies, monitor their implementation and assess their effects, with a particular focus on Climate Change. This monitoring is a necessary complement to prediction systems and most GMES services associate both.

The IPSL laboratories participate to this monitoring through the respective “Observatoire des Sciences de l’Univers” set up in the Paris area, and the “labelled “ observation services that they take in charge recurrent measurements, in the ocean or over the continents. Some of the EquipEx projects in which IPSL is actively involved (SOFRA-EX for Lidar networks, including the SIRTA supersite run by the IPSL; GHG-Scope concerning Greenhouse gases) contribute to this monitoring

In addition to these EquipEx proposals, other monitoring activities should be favoured by the L-IPSL and offer new services. For example, IPSL laboratories (as mentioned above) are already involved in the GMES Atmospheric service, which distributes past and present records of atmospheric composition, together with forecasts and reanalyzes of air quality over Europe. This service also provides support to climate change studies by providing a long-term monitoring of the atmospheric concentration in carbon dioxide, methane, aerosols and some estimate of their surface fluxes. These atmospheric GMES services will be enhanced by the L-IPSL project (see WP-1), with a special effort to produce analyses of atmospheric CO_2 and CH_4 and their surface fluxes, for running periods of 6 months behind real time.

Links to new structures for innovation

Research, observations, models and simulations produced at IPSL will feed the development of end-user climate services at a rather national level, with long-term partnership with Meteo-France that will be in particular used for pilot projects with industry and SMEs through the IEED CLAIRE. The IEED CLAIRE project, if funded, aims at developing innovation for climate adaptation and mitigation using in particular the IPSL tools for climate and air pollution monitoring and anticipation. Through the development of targeted pilot projects with industry within CLAIRE, the IPSL will contribute to develop applications such as

the energy sector, with the evolution of heat/cold extremes and energy resources (see Sections A3 and A4),

air quality and the emissions abatement regulation, with an effort being put on evaluating co-beneficial (climate – air quality) emission scenarios

the carbon market and the development of sensors, with the development of regional carbon cycle accounting services using both observations of greenhouse gases from the ICOS infrastructure.

At European level, the Climate KiC will also help develop projects linking research, innovation and training, with the aim of fostering climate adaptation and mitigation. The KiC will help to develop application projects together with European partners and industry.

Finally, in several areas, direct collaborations with agencies or industries are present and will be strengthened. Such is the case of climate change impact on hydrology. For water resource management, the primary indicator will be the change in mean river discharge, which can be combined to demographic data to construct the widely used water scarcity index (*Vorosmarty et al*., *2000*). Other useful indicators relate to extremes flows (exceed thresholds and probabilities), whether high flows regarding flooding vulnerability or low flows for water resource sustainability, but they carry much larger uncertainties. The challenge be to devise the appropriate transfer to end-users, which routinely use the corresponding present time indicators for very specific dimensioning.

Over the last decade, Sisyphe, one of the new partners of L-IPSL, has for instance pioneered multivariate analyses of climate change impacts on river systems (river regimes, ground water, water temperature and water quality). Care has been taken to regularly communicate the results to the involved stake-holders, whether public (Ministry of Environment, ONEMA, water agencies, planning and navigation agencies, local actors) or industrial (water delivery, water treatment, consulting and engineering firms, innovative SMEs). This communication, mainly based on workshops and meetings giving voice to stake holders, has proved very fruitful to progressively broaden their audience and highlight new applied research questions (such as the consequences of climate change on hydraulic management, or air conditioning activities, from needs in large cities to the cooling potential of rivers).

Annexe III: Education et formation professionelle

The present involvement of L-IPSL laboratories into Higher Education

The partners of L-IPSL occupy a prominent position for higher education in environmental sciences in *Ile de France*, with more than 130 teachers-researchers, 170 researchers, and 220 engineers and technicians. This unique human potential, associated with the large experimental and modelling capacities of the L-IPSL partners, allows, each year, tens of thousands of hours of teaching to be given and hundreds of PhD and master students to be trained in the high level masters and doctoral schools driven by the universities and graduate schools (Grandes Ecoles) supporting L-IPSL, 5 of which being listed in the Shanghai academic ranking of world universities.

Masters (and equivalent) under the responsability of L-IPSL people	Accrediting organisms	L-IPSL implication	Research / Pro
AIR : Atmosphère et Qualité de l'Air	UPD, UPE-C, ENPC	LISA	R & P
Arctic Studies *	UVSQ	LSCE, LATMOS	P
ECH : Environnements continentaux et hydrosciences (5 parcours)	UPMC, UPD, Mines ParisTech, Agro ParisTech, UPE-MV	SISYPHE, LSCE, IDES, LMD, LATMOS	R & P
Ecole d'ingénieur Polytech'Paris, spécialité Sciences de la Terre	UPMC	SISYPHE, LOCEAN	P
Environnement sédimentaires et volcaniques	UPSXI	LSCE	R
Génie Géologique	UPSXI	IDES	P
Géosciences (5 parcours)	UPMC, MinesParistech, CNAM, ENS	SISYPHE, LMD, LATMOS	R & P
H2S: Hydrologie, Hydrogéologie et Sols	UPSXI	IDES, LSCE ??	R & P
ICE : Interations Climat Environnement	UVSQ, INSTN	LSCE, LATMOS	R
MAPE : Matériaux du Patrimoine dans l'Environnement	UPD, UPE-C, ENPC	LISA	R & P
MECE : Management de l'Environnement pour les Collectivités et les Entreprises	UPD, UPE-C, ENPC	LISA	P
MPE Mécanique et Physique pour l'Environnement.	Ecole Polytechnique	LMD	R & P
OACOS : Océans, Atmosphère, Climat, et Observations Spatiales (4 parcours)	UPMC, ENS, Ecole Polytechnique, ENSTA, Ponts ParisTech	LMD, LOCEAN, LATMOS, LPMAA	R
OEM : Océanographie et Environnement marin	UPMC	LOCEAN	R
QUALUB : Qualité de l'air et lutte contre le bruit	UVSQ, CNAM	LSCE, LATMOS	P
Parcours régional en Planétologie	UPMC, UPSXI, UPE-C, UPD, UVSQ, MNHN, OP, IPGP	LATMOS, LMD, LISA	R
SPE : Sciences et Politiques de l'Environnement	UPMC, SciencesPo	LATMOS, LMD	P
TRIED : Traitement de l'information et exploitation des données	UVSQ, CNAM, Telecom-sud Paris	LATMOS, LOCEAN	P
Masters with a significant participation of L-IPSL people	**Accrediting organisms**	**L-IPSL implication**	**Research / Pro**
AEGR : Analyse économique et gouvernance des risques	UVSQ, INSTN	LSCE, LATMOS	P
CDEQ : Construction Durable et Eco-Quartiers	UVSQ	LSCE, LATMOS	P
ECONOVING *	PRES Universud Paris	LSCE, LATMOS, IDES	P
EMBS (Erasmus Mundus Marine Biodiversity and Conservation) *	UPMC, Universities of Ghent, Bremen, Algarve, Oviedo, Klaipèda	LOCEAN	R&P
Double Diplôme master environnement UPS - Université polytechnique de TOMSK (Russie) *	UPSXI	IDES	R & P
MCE : Médiations des connaissances environnementales	UVSQ	LSCE, LATMOS	R & P
RSE : Stratégies de Développement Durable et Responsabilité sociétale des entreprises	UVSQ	LSCE, LATMOS	P
SAGE : Système Aquatique et Gestion de l'Eau	UPD, UPE-C, ENPC	LISA	R & P
SSENTS : Sciences de santé environnement territoires et santé	UVSQ	LSCE, LATMOS	P
TGAE (Télédétection et Géomatique Appliquées à l'Environnement)& TAPE (Télédétection Appliquée aux Problèmes d'Environnement)	UPMC, UPD, UVSQ,	LMD,	R & P

Table 1: Masters associated to L-IPSL

L-IPSL partners promote and teach a comprehensive and quantitative approach of the climate system, concerning all its components, at all time and space scales. This involves many disciplines (physics, chemistry, mathematics, biology, geosciences, engineering sciences), which cover a large continuum from theory to experiment, and increasingly extend to the human dimensions of the environmental problem. This large variety of approaches permits the coexistence of disciplinary and multidisciplinary masters, concerning the study of the Earth and other planets, the physics and chemistry of the climate system, the global and local aspects of air or water pollutions, the impacts of anthropogenic and climate forcing on the natural resources, the links between climate, economy, and society, … Besides the involvement of its academics and staffs in teaching, IPSL also provides a financial support for innovative teaching in environmental sciences through a yearly call for proposals.

The master studies are distributed over the different universities and Grandes Ecoles to which the L-IPSL laboratories are affiliated (Table 1). The doctoral studies are distributed over a few Ecoles Doctorales, with ED129 (*Sciences de l'Environnement en Ile-de-France*) playing a central and unifying role. Other doctoral schools associated to L-IPSL provide a deeper insight into geosciences, hydrology, natural resources, energy, urban territories, instrumental physics, and space sciences. (Table 2). L-IPSL partners also support international summer schools for young scientists and provide information to a wider public, through the "Fête de la Science", through dedicated courses for professionals (high-school teachers, private company executives…), through regular seminars, and they participate to the design of on-line sites of information (e.g. climate FAQ on www.ipsl.fr). L-IPSL people are involved at an individual level into the diffusion of scientific information (through book writing, or interviews in different communication media).

Doctoral schools	Accrediting organisms	Associated organisms	L-IPSL implication	Number
Sciences de l'environnement d'Ile de France	UPMC, UVSQ, ENS	UPD	LMD, LATMOS, LSCE, LISA, LPMAA, LOCEAN	ED 129
Modélisation et Instrumentation en Physique, Energies, Géosciences et Environnement	UPSXI	UPMC, UVSQ, ENS	IDES, LSCE	ED 534
Géosciences et ressources naturelles	UPMC, Mines ParisTech, Agro ParisTech	IFP, Ec. Natio. Sup. Pétrole et moteurs	LSCE, SiSYPHE	ED 398
Ecole doctorale de l'Ecole Polytechnique	Ecole Polytechnique		LMD, LSCE	ED X
Astronomie et astrophysique IDF	Obs. Paris, UPMC, UPD, UPXI	Univ. Cergy Pontoise, UVSQ, ENS, INSTN	LATMOS, LISA	ED 127
Sciences, ingéniérie et environnement	PRES Paris Est		LISA	ED 531
Doctoral Programme on Marine Ecosystem Health and Conservation	UPMC	UPMC, Universities of Ghent, Bremen, Algarve Oviedo, Klaipèda,Pavia, Bologna, Plymouth	LOCEAN	ERASMUS MUNDUS
La Physique de la Particule à la Matière Condensée	UPMC	ESPCI	LPMAA	ED 389
Sciences et technologies de Versailles	UVSQ		LATMOS	ED 539

Table 2: Doctoral schools associated to L-IPSL

The added value of the L-IPSL project

The objective of L-IPSL, in this very active education and training ecosystem, is to provide bridges between a continuously evolving science, a multi-actor higher-education system, and the increasing demand of knowledge from various sectors of the society. The fast expansion of the international dimension of research and education, with a constant motion of students and post-docs between the major laboratories around the world, exists in all scientific fields but it is especially strong in the context of climate studies, whose aim is precisely to study the Earth environment. L-IPSL partners are already leading several international masters, taught totally or partially in English (Table 1).

During the next decade, the needs for education and training on environmental changes should increase largely, because political and economical decisions will have to take global changes into account from global to local scales. This will concern all aspects of our socio-economic system, from citizens to governments, from start-up initiatives to international companies. Therefore, the masters involving L-IPSL partners are not restricted to climate sciences, but already include several professional masters opened to students from human sciences (Table 1). Confronting these needs requires a joint and multidisciplinary reflexion between all actors involved in higher education and professional training.

In this very broad context, our ambition is to use the strengths and dynamics of the universities and *Grandes Ecoles* associated L-IPSL to create a leading international actor for the academic and professional formation on climate sciences, with capabilities to develop new links with other disciplines, foreign universities and private partners. **L-IPSL will facilitate in priority a few concrete and original actions, with high leverage capabilities, which will be endorsed and realized in synergy with the involved Universities and Grandes Ecoles**. Such synergies already exist (e.g. ENSTA/Ecole Polytechnique/UPMC/ENS/PontsParisTech for master OACOS, UVSQ/ENSTA for master ICE, UPMC/AgroParisTech/MinesParisTech for master ECH, UPEC/UPD/PontsParisTech for masters AIR-MECE-SAGE-MAPE, see table 1) but need to be further developed and coordinated.

In full consistency with the five axes of the research project (§5.2.1), education actions promoted by L-IPSL will be focused on the specific questions of climate change for the next decades, at global and regional scales, addressing the issues of natural resources (availability, impacts, and feedbacks), and of emerging risks. The triptych Climate-Resources-Risks is the red wire of our proposition. These three notions are associated in all processes of environmental decision-making. They are also linked by the same concept of uncertainty which underlies the L-IPSL project: how can we separate what is known with certainty, from what is so far unpredictable? Recent debates have shown to which extend an education to these issues must be based on a solid scientific culture, and how much it is needed.

L-IPSL proposes to develop sustainable actions in higher education (over the 10 years of the LabEx), complemented by a few fast-track actions delivered after two years.

Development of the international dimension of graduate level education.

The first initiative will be to help **developing the international dimension of existing masters, and to favour an increased educational offer to non-French speaking students**, in synergy with associated establishments (see §5.2.5: Attraction section). The second initiative will be to **train PhD students and young scientists** more actively on emerging topics related to climate-resources-risks. This will be achieved through **regular international thematic schools**, with lectures by the best international specialists from research institutes and innovative companies. These schools will also be opened to international participants and to scientists at the interface of the climates sciences.

These two initiatives will be developed consistently with other national and international projects in which IPSL is already involved, such as the European Climate KIC or IEED French initiative, the current Erasmus Mundus actions, or the existing industrial chairs (e.g. Econoving at UVSQ or Sustainable development at Ecole Polytechnique). They will include innovative teaching approaches such as e-learning modules for higher education. They will be presented more systematically for funding at European or international levels (EU call on formations, Erasmus Mundus, …), or at a national level from industrial chairs and foundations, in order to de-multiply the L-IPSL human and financial support.

Asserting a discipline through the diffusion of teaching and communication material

During the last decade, the L-IPSL partners and researchers have developed a large amount of teaching and communication material on all the facets of the Earth Environment system – this is associated with the development of a discipline we may call Climatology or “Earth System Sciences”. This includes courses, lab works, field works and internships, documents for students, books for a wider audience, essays, discussion with journalists. These elements have now reached a high degree of maturity and deserve improved visibility and recognition.

L-IPSL will **gather and synthesize the existing teaching in a series of published reference textbooks and of online books on Climate-Resources-Risks**, visible and accessible worldwide. The publics targeted in priority are higher education students, scientists, and multipliers of the society (trainers, teachers, policy makers, team leaders, …). This ambitious effort is compulsory and can be done efficiently in a coordinated way only. Editing such books (by opposition to publishing them) can come only from a concerted action from a scientific collaborative project such as L-IPSL.

Professional insertion and training

Recent enquiries about the professional insertion of graduate students 30 months after completion of a master in sciences associated to L-IPSL show excellent results with more than 75% occupying a permanent position, mostly in services (30-35%), in the public sector (15-30%) and in industries (7-25%). Another enquiry concerning PhD students from the doctoral school “Sciences de l’environnement d’Ile de France” has shown in 2007 that, 76% had a permanent position (private sector, higher education and research, administration and secondary education), 21% were carrying out a post-doc mostly in foreign countries, and only 3% were still looking out for an employment.

From these figures, but also from the prominent place of environmental problems in our society, symbolized by the two “Grenelle de l’environnement”, it is doubtless that the environmental sciences will constitute a growing source of employment opportunities for students, but also for the working professionals. Indeed, higher education and professional training should now be considered as a continuum during one’s life. This fact will constitute a major concern for L-IPSL, its researches will constitute a central foundation of this process.

A co-ordonated offer of doctoral modules and professional trainings will be developed in collaboration with the universities and Grandes Ecoles of L-IPSL and their private or public partners. **L-IPSL will coordinate and accompany multiday sessions for key influencers** with significant reach and impact in educational and technical institutions, associations, regional and national agencies or companies. These attendants should in turn act as multipliers by further diffusing the knowledge and skills learned in L-IPSL within and through their own organisations. Experimental and modelling capacities of L-IPSL will be associated to the sessions whenever it is possible. **Dedicated sessions for PhD students will also be proposed** to illustrate the variety of existing and potential opportunities inside and outside L-IPSL.

Expected results, fast-track products, and means

The success of these three educational objectives - International visibility at graduate and doctoral levels, edition and communication, PhD and professional training - will be assessed through a set of visible deliverables. Within 10 years L-IPSL intends to have:

improved the international visibility of L-IPSL universities and Grandes Ecoles with more international students in the masters and renewed contents, completed by regular attractive international thematic schools;

- edited a textbook & ebook collection dedicated to a quantitative description of the “Earth system sciences”;
- developed a regular offer for PhD education and professional training built on the skills of L-IPSL and in synergy with its public and private partners.

Within 2 years, L-IPSL will deliver, as fast-track products favouring the development of the long-term objectives:

- the identification of an international education path on Climate-Resources-Risks in existing masters of L-IPSL, and its promotion at an international level.
- a homogeneous set of 50 laptop easily deployable for education actions promoted by L-IPSL.
- e-communication rooms: an internal network will be created between L-IPSL partners, with rooms equipped using pioneering technologies allowing multisite videoconferencing, virtual and e-learning classes, document exchanges, shared digital whiteboards, …

The success of both short-term and long-term objectives depends critically on adequate resources, both on human side (three full-time persons seems is an absolute minimum to coordinate and develop the proposed actions), and financial side (see §6.1.2).

Annexe IV: Références

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